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NATIONAL BUREAU OF STANDARDS REPORT

8352

PERFORMANCE OF ROOFINGS ON GUAM, M.I. AND OKINAWA, R.I.

by

William C. Cullen

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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PERFORMANCE OF ROOFINGS ON GUAM, M.I. AND OKINAWA, R.I.

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Building Research Division

Sponsored by

Office of the Chief of Engineers
Department of the Air Force
Bureau of Yards and Docks

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PERFORMANCE OF ROOFINGS ON GUAM, M.I. AND OKINAWA, R.I.

1. INTRODUCTION

The National Bureau of Standards was requested by the Bureau of Yards and Docks, U. S. Navy; the Directorate of Civil Engineering, U. S. Air Force; and the Corps of Engineers, U. S. Army; to provide technical assistance in a program to obtain performance data on roofing systems exposed in tropical areas. The study was precipitated by the many premature failures of roofings on both Guam and Okinawa, resulting in abnormally high maintenance and replacement costs. A survey of roofing systems on Guam and Okinawa was conducted as a task under Project 10447, Performance of Roofings, of the Tri-Service Engineering Investigation of Building Construction and Equipment during April 6 to April 19, 1964 to develop data to assist those charged with design, construction and maintenance responsibilities.

The conduct of the survey consisted of "on the roof" observations of typical roofing systems protecting structures on Army, Navy, Marine, and Air Force installations. Personal contacts were made with roofing contractors and military and civilian engineers experienced with construction performance and maintenance of roofings.

This report includes our observations of the performance of roofing systems on Guam and Okinawa, as well as our opinions and suggestions relating to past and predicted performance of specific roofing systems.

Another purpose of the investigation was to provide technical assistance to agencies of the Defense Department in connection with an evaluation program of new roofing systems on Guam Island as proposed by the committee members of Task 30 of Project 32. The importance of this phase appears sufficiently significant as to warrant a separate report which will be submitted in the near future.

2. GUAM, MARIANA ISLANDS

2.1 Climatological Data

The climate of Guam is uniformly warm and humid throughout the year. Temperatures during the day are typically in the middle or high 80's and nighttime temperatures fall to the low 70's or high 60's. The relative humidity commonly ranges from 65 - 75% in the afternoon to 85 - 100% at night.

The mean annual rainfall ranges from about 80 inches along the coast of the western side of the southern half of the island to about 95 inches on the windward (East) side.

The dominant winds are the trade winds which blow from east or northeast with common wind speeds of 15 - 25 mph during the dry season. Occasionally there are typhoons and these bring not only tremendous rains, but violent winds. For example, during typhoon "Karen" on 11 November 1962 the sustained winds were measured at 180 mph with gusts up to 207 mph. It was interesting to note that the U. S. Weather Bureau states that the chances of having a typhoon pass close to Guam in any particular year are 1 in 3 while the chances of having a typhoon move directly across Guam are only 1 in 8.

2.2 Roofing Systems and Their Performance

2.2.1 Bituminous Built-Up Roofs

Asphalt built-up roofs have been used to protect permanent military structures on Guam since the end of World War II. The roof decks of these buildings generally consisted of either the waffle type pre-cast concrete slabs or the conventional poured-in-place slabs, with both types having little or no slope.

Prior to 1954, the built-up membrane consisted of multiple plies of an asphalt-saturated asbestos felt using an abnormally high softening point asphalt (200 to 240°F) as the plying cement. For the most part the membranes were applied over a vegetable-fiber insulation board and were surfaced with an aluminum coating. This type of roofing system gave poor service since they required extensive maintenance and failed within a few years. An extensive investigation of roofings on Guam by the author in 1954 attributed the deficiencies as evidenced by blistering, cracking, and general deterioration, to excessive moisture in the deck and insulation, to the use of insulation resulting in high roof temperatures, and to the use of the high softening point asphalt. Figure 1 illustrates typical weathering pattern of roof surface as observed in 1954, while Figure 2 illustrates the difference in weathering of roofing insulated from the deck and that applied directly on the concrete. As a direct result of the investigation the smooth surfaced roofs were replaced with coral-surfaced asphalt built-up roofs applied with a 170 - 190°F softening point asphalt directly to the concrete deck.

Our observations during the April 1964 inspections indicated that the coral-surfaced, bituminous built-up roofings have given satisfactory service after as long as 10 years exposure, and they have by far out performed their smooth-surfaced counterparts. Although asphalt has been the bitumen predominately used and has served well, an experimental roof at the Naval Communication Center using coal-tar-pitch as the bitumen has also performed well after 10 years exposure as illustrated in Figure 3. Figures 4, 5 and 6 illustrate the condition of typical coral-

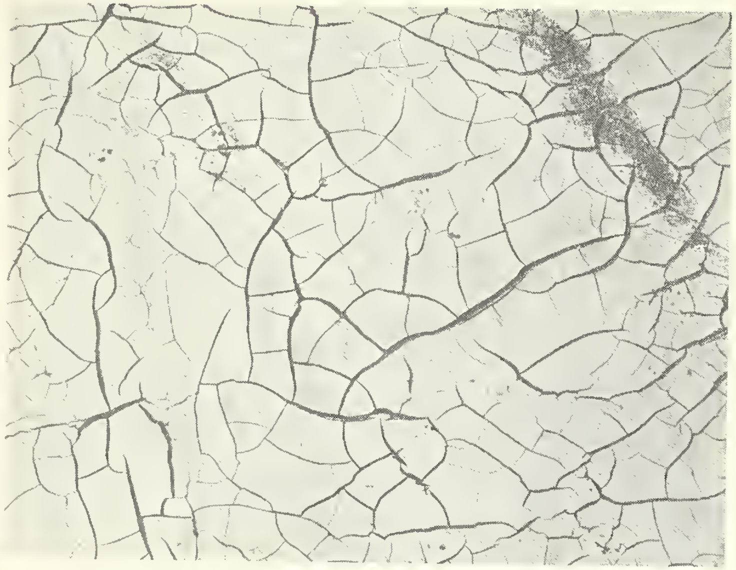

FIGURE 1. WEATHERING PATTERN, ASPHALT-SURFACED ROOF ON GUAM OBSERVED IN 1954.

FIGURE 2. DIFFERENCE IN WEATHERING ATTRIBUTED TO USE OF INSULATION.

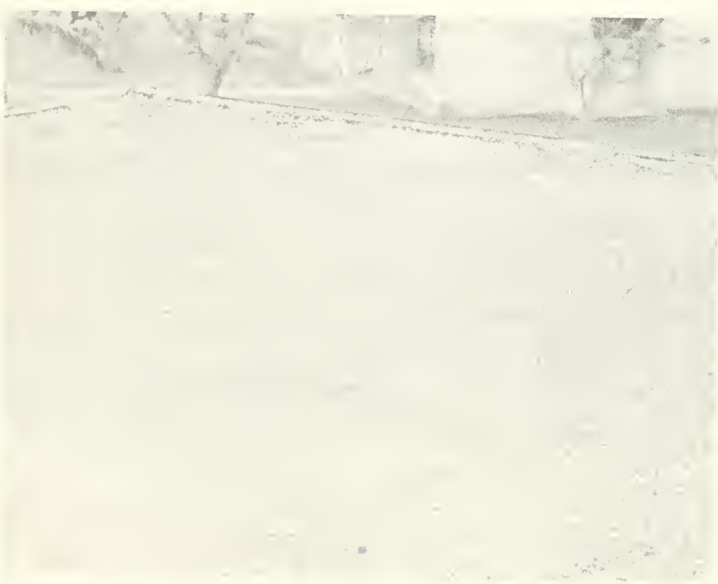

FIGURE 3. COAL-TAR-PITCH BUILT-UP ROOF AFTER 10 YEARS EXPOSURE ON GUAM.

FIGURE 4. CORAL-SURFACED BUILT-UP ROOF, OROTE POWER PLANT, GUAM. AGE: 10 YEARS.

surfaced built-up roofs on the Orote Power Plant, the U. S. Naval Hospital, and the Fleet Laundry which have served very satisfactorily after 10, 8, and 7 years, respectively. However, it was observed that each of these roofs required immediate preventive maintenance as exemplified by the area shown in Figure 7. Figure 8 shows the gradation of the manufactured coral aggregate and the excellent coverage obtained with this material on the hospital roof. Similar service was obtained from surfaced built-up roofs observed on the Commissary Building and the CE Shops Building at Anderson Air Force Base.

The good performance of these roofings was attributed to the use of mineral surfacing, to the elimination of insulation from the top of the deck, and to the use of a softer asphalt.

It should be pointed out that the use of surfacing aggregate for built-up roofs has not had universal acceptance on Guam due to its reported vulnerability to blow off during high winds and the damage caused by flying gravel. Although this criticism may be justified to some extent, especially during typhoons, we cannot agree in toto with the opinion that this shortcoming is sufficient to limit its use.

In way of summary, we believe that the coral-surfaced bituminous built-up roofing has given the better performance among the organic roofings employed on Guam Island from both a service and maintenance standpoint. However, we observed that many such roofs are in need of immediate preventive maintenance to insure continued good service. The need for periodic inspections and timely maintenance cannot be overemphasized.

2.2.2 Exposed Concrete Roofs

Since the early 1950's many engineering personnel have advocated the use of the exposed concrete deck as the weather surface due to the poor performance of most organic roofing systems. A distinction must be made here between the pre-cast and the poured-in-place decks.

The use of the pre-cast roof decks as the weather surface has resulted in both success and failure. For example, a prematurely failed built-up roof was removed from the Orote Power Plant in 1953 and the inter-panel joints between slabs were treated with a fatty-acid-pitch base sealant. Unfortunately, this material failed within six months due to a separation from the concrete causing severe leakage which required the immediate reapplication of a multiple-ply roof membrane. As a matter of interest, this roofing is still performing satisfactorily as described in paragraph 2.2.1. On the other hand, a weather-resistant and leakproof roof was obtained on the Bachelors Officers Quarters, Naval Communication Station, Finegayen, on which the inter-panel joints were treated with a hot-poured

FIGURE 5. CORAL-SURFACED BUILT-UP ROOF, U. S. NAVAL HOSPITAL. AGE: 8 YEARS.

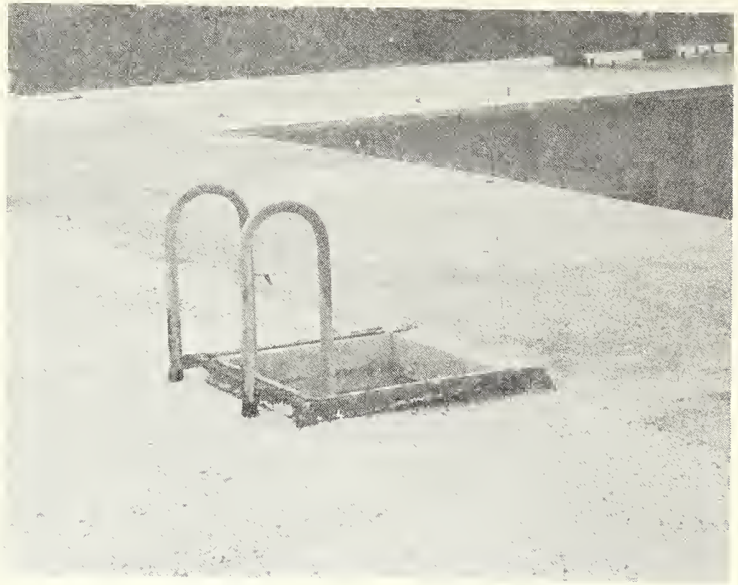

FIGURE 6. CORAL-SURFACED BUILT-UP ROOF, FLEET LAUNDRY. AGE: 7 YEARS.

FIGURE 7. EXPOSED FELTS WHICH INDICATE NEED FOR PREVENTIVE MAINTENANCE. OROTE POWER PLANT.

FIGURE 8. EXCELLENT COVERAGE PROVIDED BY MANUFACTURED CORAL AGGREGATE.

joint sealer (Federal Specification SS-S-164) approximately three years ago. It was reported that extreme care was exercised to prepare the concrete surface at the joint in order to obtain good adhesion. The satisfactory results are illustrated in Figures 9 and 10, which show both a general and close-up view, respectively. An examination of the interior revealed no water penetration despite the ponding water shown in Figure 9.

The poured-in-place slabs have two advantages over their pre-cast counterparts in that they have fewer joints to treat and are of greater thickness. Consequently, they have performed very satisfactorily as exposed decks for at least 10 years on Guam Island. Observations of typical slabs indicated no leakage or seepage had occurred except where structural or shrinkage cracks were evident. Figures 11 and 12 illustrate typical poured-in-place slabs which have given maintenance-free service on structures at the Naval Communication Station, Finegayen. The dark appearance of the roof on the house shown in Figure 12 resulted from a biological growth which is common to warm and humid areas.

2.2.3 Miscellaneous Roofing Systems

The multiple-ply built-up roof and the exposed concrete decks have been the predominately-used roofings on Guam. However, a number of less conventional systems were also observed during the survey. These systems have been used on both an experimental and practical basis. Those used on an experimental basis will be fully treated in a future report and the performance of those used practically are reported herein.

A roof covering, consisting of a mopping of hot asphalt at 30 to 50 lb. per square in., which is embedded with a single ply of fiberglass base sheet and coated with a white vinyl emulsion paint, has been employed on a number of roofs at Anderson Air Force Base. For example, in one case it was used to replace built-up roofing that was severely damaged during typhoon "Karen" on the Meehan Theater and Building 21000. In another case it was used to protect a poured-in-place deck which developed small cracks due to the vibrations produced by jet aircraft.

Our observations indicated that this system has performed adequately during its one year exposure. The apparent high solar reflectance of the white emulsion contributed to the relatively cool roof temperatures which were experienced. There was some evidence that the emulsion coating was susceptible to attack by fungus, especially in shaded areas where water collects and stands. The performance of this system must be considered satisfactory to date. Nevertheless, we believe it is difficult to project its future performance based on such a short-time exposure. It is questionable whether the experience to date is sufficient to warrant its extended use on Guam.

FIGURE 9. TREATMENT OF INTER-PANEL OF PRECAST DECK WITH HOT-POURED JOINT SEALER. AGE: 3 YEARS.

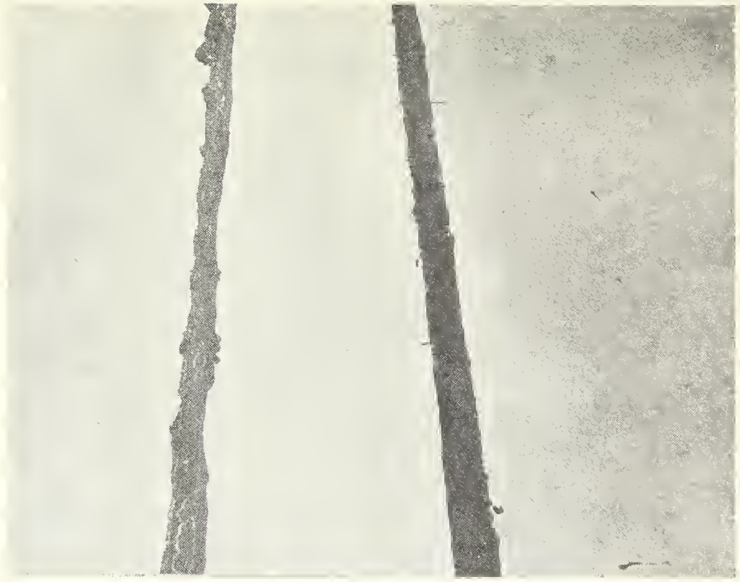

FIGURE 10. CLOSE-UP OF JOINT SHOWN IN FIGURE 9.

FIGURE 11. EXPOSED POUR-IN-PLACE CONCRETE DECK, BOQ, NCS, FINEGAYEN, AGE: 3 YEARS.

FIGURE 12. POUR-IN-PLACE CONCRETE DECK. AGE: 10 YEARS.

The performance of another unconventional roofing system used to protect over 1000 units of Capehart Housing at Anderson Air Force Base has not been quite so successful. Originally an aluminum coating was specified to protect the poured-in-place decks for reflectance and aesthetic purposes only. However, cracking sufficient to cause leakage, developed in the slabs which required additional waterproofing of the slab. As an economy measure a roof covering of hot asphalt (35 - 50 lb./sq) surfaced with an aluminum coating was used.

A critical examination of several roofs revealed severe blistering of the asphalt and cracking and alligatoring of the aluminum coating after about 5 years exposure. In addition, engineering personnel reported that over 30 complaints of leakage have been recently received from residents of the area.

It was obvious to even those uninitiated in roofing performance that this system was not sound. It not only failed in its primary function to waterproof the roof deck, but now presents a costly task to remove and replace. A multiple-ply bituminous built-up roof appears to offer the only logical system.

2.2.4 Non-Military Roofings

It was interesting to note that a large percentage of civilian structures were roofed with corrugated galvanized steel roofing which has apparently served well on sloping decks and has required little maintenance. However, the corrugated metal roofings were particularly vulnerable to high winds and, it was reported, that many such roofs were severely damaged or destroyed completely during typhoon "Karen".

3. OKINAWA, RYUKYU ISLANDS

3.1 Climatological Data

The Ryukyu Islands are located within the temperate zone. Nevertheless, the warm Japanese current provides a mild climate. The yearly temperature averages 72°F with a high of about 89°F during the summer and a low of 61°F during the winter. The relative humidity is high and varies from a low of 61% during the winter to a high of 89% in the summer, with an average of 76%.

The rainfall is quite heavy with a yearly average of 82 inches. The summer months have the heaviest rainfall, although a minimum of 4 inches falls even in the driest months.

Okinawa, like Guam, is subject to relatively high winds and occasionally there are typhoons which are not only accompanied by very heavy rains, but also by violent winds.

3.2 Roofing Systems and Their Performance

3.2.1 Bituminous Built-Up Roofs

Smooth-surfaced, asphalt built-up roofs have been used to some extent on Okinawa to protect both pre-cast and poured-in-place concrete roof decks. The roof areas covered with such systems varied from 12 squares for a single family dwelling to over 2000 squares for large warehouses (as illustrated in Figures 13 & 14) and had roof slopes from flat to one inch per foot. Coal-tar-pitch has not been used to any extent for roofing on Okinawa.

Surfaced, built-up roofs have been used only to a very limited extent due to the vulnerability of the gravel surfacing to blow off during relatively high winds frequently experienced on the island. In many cases, an aluminum coating has been used in lieu of mineral surfacing to protect the bitumen and to provide for solar reflectance. The use of insulation between the membrane and the deck has also seen only limited application since reflective coatings have provided the necessary thermal characteristics of the roofing systems.

We have also included under this category a somewhat unconventional system consisting of two plies of a glass mat - asphalt emulsion which was surfaced with a ply of woven glass fabric coated with an aluminum coating. This roof was used to protect ranch type homes in the Sukiran Area which were completed in 1953.

The performance of the conventional smooth-surfaced asphalt built-up roofing on Okinawa appeared to be somewhat less satisfactory than that which would be normally expected of similar roof coverings in the continental United States. On the other hand, we believe they have performed better than similar roofs have on Guam Island. The severe and premature weathering of the surface protection appeared to be the most serious deficiency which will result in early failure if timely and adequate maintenance are not provided. This condition is illustrated in Figures 15 and 16 which are photographs taken of an Engineering Warehouse in the Machinato Service Area after only 2 years exposure. Figures 17 and 18 illustrate typical weathering of an aluminum-surfaced asphalt built-up roof on a Type C home in the Sukiran Housing Area after about 10 years exposure. Although these examples were typical of the surface deterioration which occurred, it was interesting to observe that the asphalt was soft and pliable, even in areas where water collected and stood, and appeared to be of good quality.

Moderate to severe blistering was also observed on many of the built-up roofs, which, no doubt, resulted from excessive moisture in some component of the roof system. Although this was a common deficiency, we

FIGURE 13. HOUSING, SUKIRAN AREA, OKINAWA.

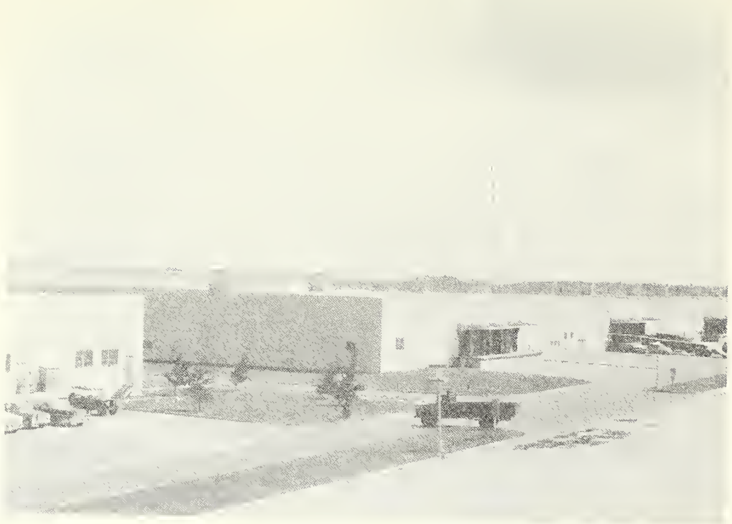

FIGURE 14. ENGINEERING WAREHOUSES, MACHINATO SERVICE AREA, OKINAWA.

FIGURE 15. SMOOTH-SURFACED ASPHALT BUILT-UP ROOF AFTER 2 YEARS EXPOSURE.

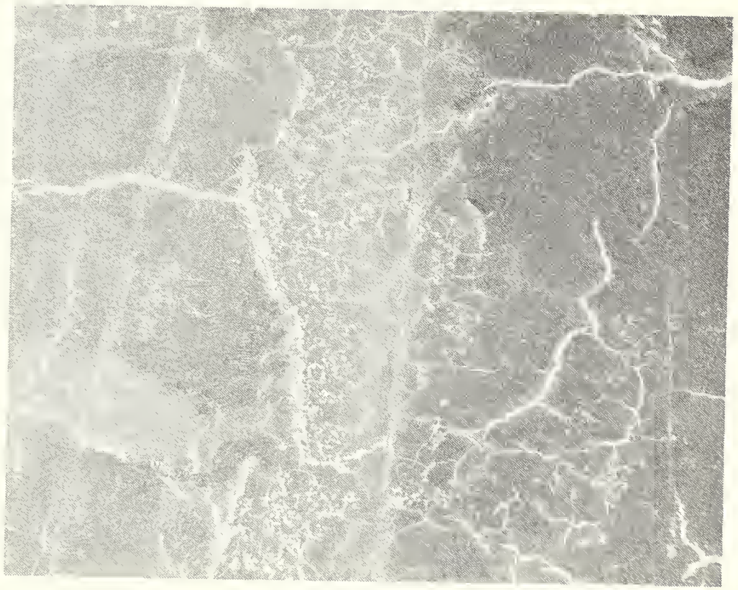

FIGURE 16. SURFACE DETERIORATION OF BUILT-UP ROOFING AFTER 2 YEARS EXPOSURE.

believe that it did not substantially contribute to premature failures. Examples of this defect were observed at Fort Buckner as illustrated in Figure 19 after 9 years exposure and on the built-up roof of the prototype barracks building (Figure 20) located at Camp Butler as evidenced by the numerous repaired areas shown in Figure 21.

Although our observations indicated that the smooth surfaced, built-up roof performance was less than satisfactory we believe this roofing has proven to be more effective than most other systems in obtaining a watertight system. Further, based on our observations on Guam, we believe the performance of a built-up roof could be considerably improved by the use of a mineral surfacing.

The performance of the glass mat - asphalt emulsion, etc., roofing system appeared to be quite satisfactory on both sloping and flat roofs. Figure 22 illustrates a typical home protected with such a roof and Figure 23 shows the roofing after about 11 years exposure. This system required periodic recoatings with the aluminum compound.

3.2.2 Exposed Concrete Roofs

Under this category we have included the concrete decks to which have been applied non-reinforced, organic compounds for waterproofing, thermal reflectance or for aesthetic reasons.

The predominate type of roofing observed on permanent military structures on Okinawa appeared to be the exposed pre-cast concrete deck. Although a number of poured-in-place roofs were also observed. The waterproofing of the latter type presented little difficulty and typical successful roofs are shown in Figures 24 and 25. The roof illustrated in Figure 25 was coated with a vinyl emulsion for reflective purposes. A failed built-up roofing on a 165 man barracks shown in Figure 26 was removed and the poured-in-place deck was employed as the roof after the shrinkage cracks were made watertight as shown in Figure 28. The treatment consisted of embedding fibrous glass strips in a bituminous plastic cement and has proved to be quite effective.

In the case of the pre-cast roof decks, the successful treatment of interpanel joints and the frequent structural cracks in the relatively thin waffle type slabs presented a rather difficult problem to those charged with design and maintenance responsibilities. A case in point was a typical barracks building at Camp Hansen shown in Figure 27. The interpanel joints were treated with a bituminous material into which was embedded woven glass fabric and the entire roof surface, including the taped joints, was surfaced with an aluminum coating. Leakage was reported to have occurred in these buildings and based on our observations,

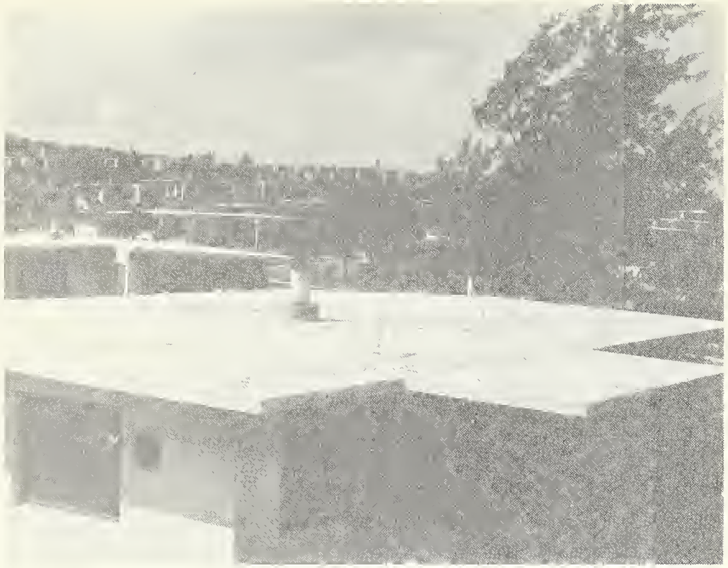

FIGURE 17. BUILT-UP ROOFING ON TYPE C HOUSING, SUKIRAN AREA.

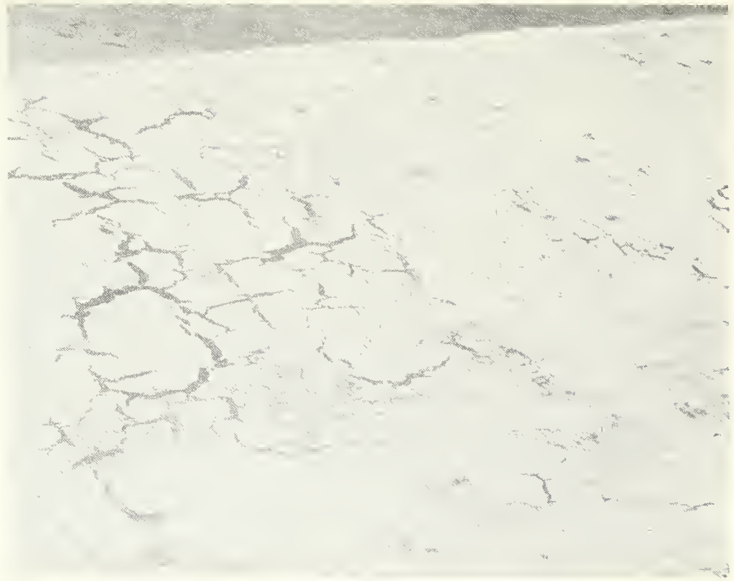

FIGURE 18. WEATHERING OF ALUMINUM-SURFACED ASPHALT BUILT-UP ROOF AFTER 10 YEARS EXPOSURE.

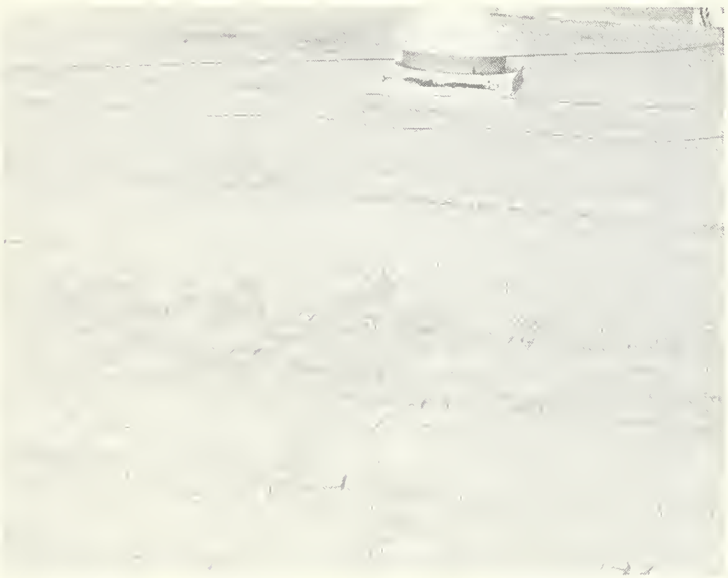

FIGURE 19. BLISTERING OBSERVED ON BUILT-UP ROOF ON EXCHANGE BUILDING, FORT BUCKNER.

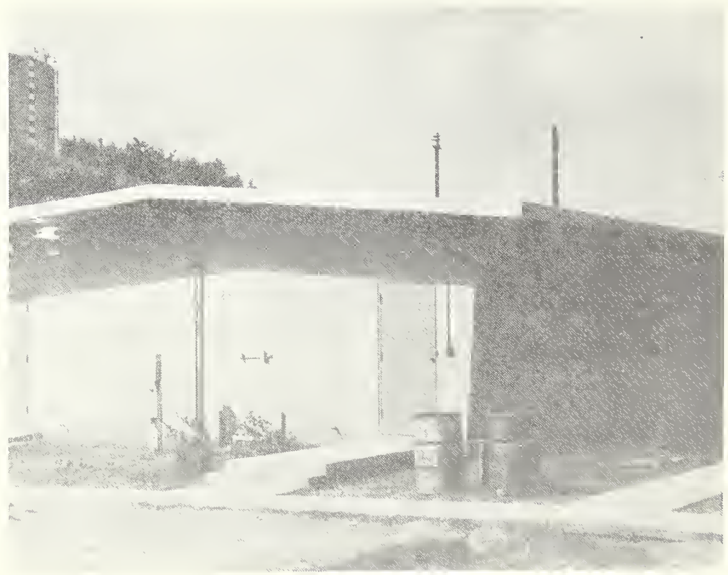

FIGURE 20. PROTOTYPE BARRACKS BUILDING, CAMP BUTLER.

FIGURE 21. ALUMINUM-SURFACED BUILT-UP ROOFING APPLIED 1957.

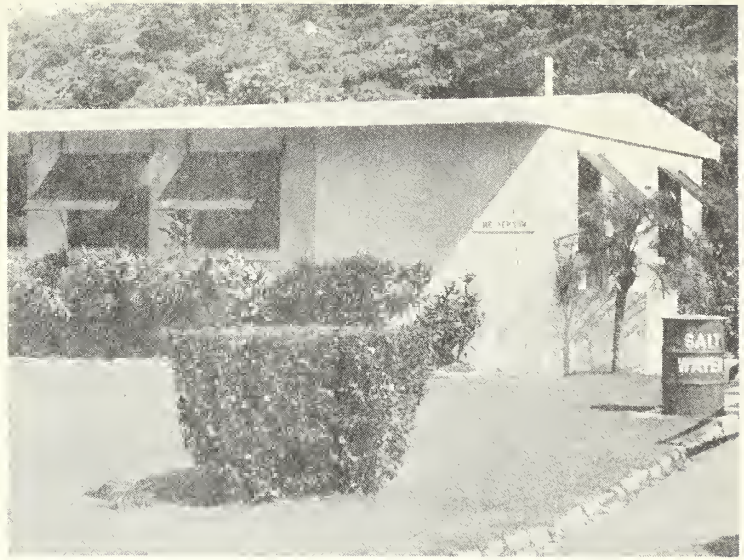

FIGURE 22. TYPICAL HOUSE, SUKIRAN AREA.

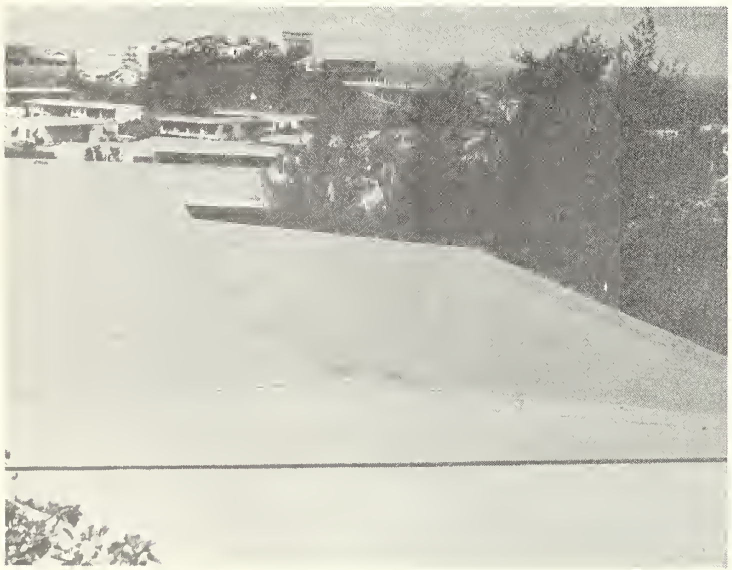

FIGURE 23. ASPHALT EMULSION-GLASS FABRIC ROOFING AFTER 11 YEARS EXPOSURE.

FIGURE 24. POURED-IN-PLACE CONCRETE DECK AFTER 3 YEARS EXPOSURE.

we believe the failure of the taping system over the inter-panel joint, as shown in Figure 29, was primarily responsible for the leakage. The continuous movement between panels due to solar heating and radiative cooling resulted in a stress concentration immediately over the joint, thus causing a failure in the taped joint. The severe embrittlement of the bituminous compound and glass reinforcing fabric due to weathering, no doubt, contributed to the failures. Engineering personnel have recognized the limitations of methods used to treat inter-panel joints and were experimenting with a number of systems as shown in Figure 30.

The aluminum roof coating appeared to be in fair condition after about 3 years exposure. Slight blistering of the coating was evident and there was some indication of erosion where the material was applied relatively thin. The definite dulling of the coating indicated a loss of solar reflectance. We would anticipate from our observations that a recoating will be necessary in a year or two.

It was reported that similar roofing deficiencies prevailed at Camp Schawb, but to a greater extent, after about 6 years exposure. The difference in performance between Camp Hansen roofings and those on Camp Schawb were attributed to improved specifications and increased inspection during application.

Our observations of the roofs on new permanent buildings at Camp Butler, which were not occupied, revealed essentially the same treatment as that observed at Camp Hansen and in our opinion similar service can be expected.

3.2.3 Non-Military Roofings

It was of interest to the author to observe the roofings used on the typical Ryukyuan homes. For the most part clay or concrete tile roofs complete with their "Kara Shishi", or Chinese Guardian Dogs, are traditional as shown in Figure 31. However, a number of thatched roofs were often seen in the rural areas as illustrated in Figure 32. These roofings have proven to be quite durable against the Okinawa weather. However, if it is of any comfort to the military engineer, these roofs also leak, are also vulnerable to damage during high winds and also require periodic maintenance.

4. CONCLUSIONS AND DISCUSSION

The intense solar radiation, the high temperatures, and the very high humidities experienced on Guam and Okinawa certainly accelerate the degradation of organic roofing materials. However, the small temperature fluctuations which occur throughout the year on these islands are conducive to good roof performance in respect to physical deterioration

FIGURE 25. POURED-IN-PLACE CONCRETE DECK SURFACED WITH A VINYL EMULSION AFTER 1 YEAR EXPOSURE.

FIGURE 26. 165-MAN BARRACKS BUILDING.

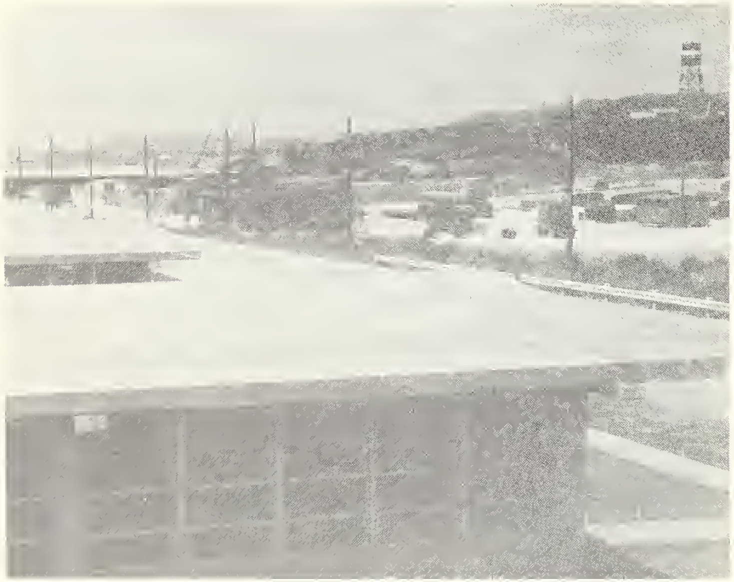

FIGURE 27. TREATMENT OF INTER-PANEL JOINTS ON PRECAST DECK, CAMP HANSEN.

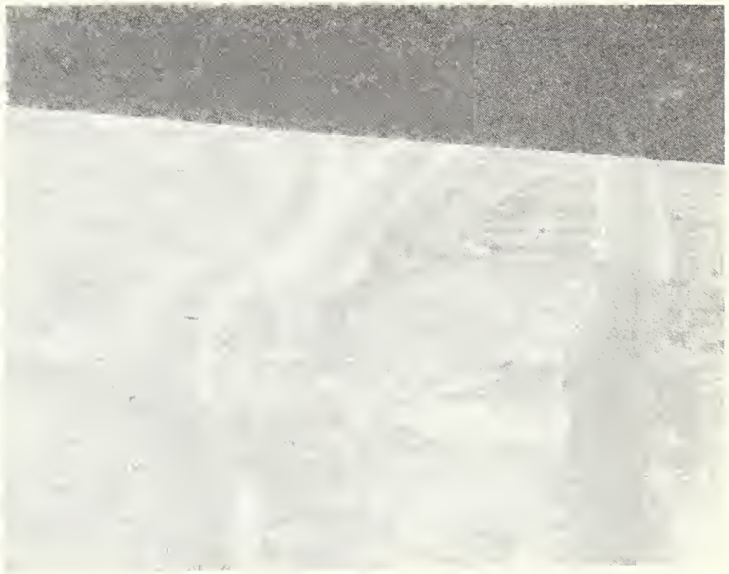

FIGURE 28. TREATMENT OF CRACKS ON POURED-IN-PLACE CONCRETE DECK ON 165-MAN BARRACKS.

FIGURE 29. FAILURE OF TAPED INTER-PANEL JOINT ON PRECASE CONCRETE DECK, CAMP HANSEN.

FIGURE 30. EXPERIMENTAL TREATMENTS OF INTER-PANEL JOINTS OF PRECAST CONCRETE SLABS.

FIGURE 31. CONCRETE TILE ROOFING COMPLETE WITH "KARA SHISHI" OR CHINESE GUARDIAN DOG.

FIGURE 32. THATCHED ROOFS OBSERVED IN RURAL AREAS.

(thermal movement, etc.). Since our experience indicates that physical deterioration of components of the roof system produce the more serious consequences, we would expect better performance in Guam and Okinawa than in areas experiencing larger temperature fluctuations.

It can be seen from the climatological data reported in paragraphs 2.1 and 3.1 that the climates of Guam and Okinawa are quite similar in respect to temperature, humidity, rainfall, and wind velocity. The intensity of solar radiation appears to be greater at Guam, but the thermal gradient to which a roof is subjected is greater at Okinawa. Nevertheless, we believe the climates are sufficiently similar as not to warrant radical changes in the design, construction, or maintenance of roofing systems. Therefore, the following discussion refers to the performance of roofing on both Guam and Okinawa.

4.1 Built-Up Roofs

For the past 10 years, the mineral-surfaced (coral) asphalt built-up roofs have given satisfactory performance on Guam with little or no maintenance. Of course, a number of deficiencies occurred in these systems, such as blistering, exposed felts due to weathering, and a loss of aggregate due to high winds, but none so serious as to affect its end use. A number of such roofs weathered the tremendous winds of typhoon "Karen" with little damage except the loss of loose surfacing. We concluded that this type of roofing has served well both from a functional and economic standpoint on Guam and believe similar service can be expected of surfaced built-up roofs on Okinawa.

Rather severe criticism has been made against the use of mineral surfacing for built-up roofs due to the damage caused by flying gravel during high winds. We have observed ample evidence that a roofing aggregate can be made resistant to blow-offs by a process described as double-surfacing and still perform its basic functions to permit the use of the waterproofing bitumen in large quantities and to protect the surfacing bitumen from destructive ultraviolet radiation. Regardless of whether the criticisms are justified or not, if a multiple-ply roof is required, one must make the choice between a smooth and a surfaced built-up roof. We know of no adequate substitutes for the aggregate surfacings.

The smooth-surfaced asphalt built-up roofs have not given adequate service either on Guam in the past or currently on Okinawa. The serious deficiencies observed were the premature weathering of the surface and blistering which occurred beneath or within the membrane. In addition, these systems required and do require more maintenance than their surfaced counterparts.

In summary, we believe that the surfaced built-up roofings will render the better service among the membrane type systems provided they are constructed of acceptable materials which are applied in accordance with good roofing practices. The bitumen, whether coal-tar-pitch or asphalt, should be specified to conform to applicable Federal, Military, or ASTM Specifications and of a softening point as low as practicable, commensurate with the slope of the roof. The reinforcing medium should consist of organic, asbestos, or glass felts treated with the appropriate bitumen and conforming to applicable Federal or ASTM Specification. The surfacing material should be manufactured of native materials (coral in Guam, crushed stone in Okinawa) and conforming as nearly as possible to the requirements of ASTM Designation D1863. We would also suggest that the use of insulation be eliminated from between the roof deck and the roof membrane.

4.2 Exposed Concrete Decks

The exposed concrete slabs have, per se, performed quite satisfactorily as roofings in Guam and Okinawa. The poured-in-place type have not presented the problems which have been encountered in the pre-cast types. In the case of the pre-cast roofing slabs, the main area of concern is the proper treatment of the inter-panel joints. Our observations indicated that the most effective and economical procedure was to treat the joint with a reinforcing fabric embedded and coated with a suitable bituminous material (we would suggest a plastic cement conforming to Fed. Spec. SS-C-153). The use of a "bondbreaker" consisting of a 2-in. wide strip of paper, plastic sheeting, etc., placed directly over the joint will eliminate a stress concentration at that point and prevent the early failures now experienced.

Some have advocated the use of a sealant to secure watertight inter-joints which have been used successfully to a limited extent on Guam and Okinawa. In this connection, we have contacted Mr. Arthur Hockman, the sealant expert of the National Bureau of Standards, who predicts that an acceptable watertight joint can be obtained by this procedure. However, he warns that proper surface treatment of the concrete is mandatory to obtain the desired results. The surface must be absolutely free from foreign matter and he suggests that it be lightly wiped with an organic solvent such as toluene prior to the application of the sealant. The sealant should be a polysulfide type conforming to Federal Specification TT-S-00227a. Mr. Hockman further suggests that a "bond-breaker" of polyethylene, aluminum foil, etc., be placed at the base of the joint to insure a proper shape factor during extension of the sealant.

Our observations indicated that both pre-case and poured-in-place concrete slabs develop cracks to some extent due to shrinkage, structural or thermal movement, etc., and methods of repair must be considered.

The maintenance engineer has two alternatives in such cases:

1. Isolate and repair each individual crack,
2. Apply a membrane over the entire roof.

It is obvious that the former method should be used as long as it is effective and economical. Now the question arises, when does it become uneconomical to isolate and repair the cracks. This endpoint we cannot define and would suggest that the opinion of the engineer responsible for maintenance and repair should largely govern.

The use of organic coatings for solar reflectance and for aesthetic purposes has been quite satisfactory on both islands. However, their value as a waterproofing medium is questionable. The acrylic and vinyl emulsions and aluminum coatings have been used predominately. It should be stressed here that any organic surface coatings will require additional applications every 3 to 5 years.

4.3 Miscellaneous Roofing Systems

In our opinion, the use of the unconventional roof systems as described in this report are not suitable for use on permanent structures. This statement is based on the poor performance of one system at Anderson Air Force Base and on the maintenance which will be required for other systems.

In connection with some of the newer one-ply systems which have been included in the Guam tests, such as:

a. polyisobutylene on asbestos felt,
b. polyvinyl fluoride on asbestos felt,
c. sheet butyl roofing,

we believe they possess good possibilities for special applications on Guam and Okinawa at this time, but sufficient exposure data have not been developed to recommend their extended use. The cost data from the Guam tests also indicate they are not competitive with conventional systems in the Pacific area.

4.4 Maintenance

We have observed on all installations a general need for roofing maintenance on all types of roofing systems. It was evident that the need for periodic inspection and maintenance was not always recognized and further, when it was, funds were not always available to implement the action.

We strongly believe that failure to recognize and correct minor defects and deterioration in its earliest stages are the greatest causes of premature roof failures and frequently result in costly repairs and replacements. We further believe that funds which are made available for inspection, maintenance, and repair programs will ultimately result in enormous savings.

4.5 Cost Data

We attempted to obtain accurate cost data in respect to roofings during the survey and based on information from numerous sources (some conflicting reports), we have established the following factors:

Guam	- 2 to 2-1/2 times average cost (California)
Okinawa	- 1-1/2 to 2 times average cost (California).

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